EnerDel Lithium Power Systems

EnerDel Technical Presentation

EnerDel Lithium Power Systems

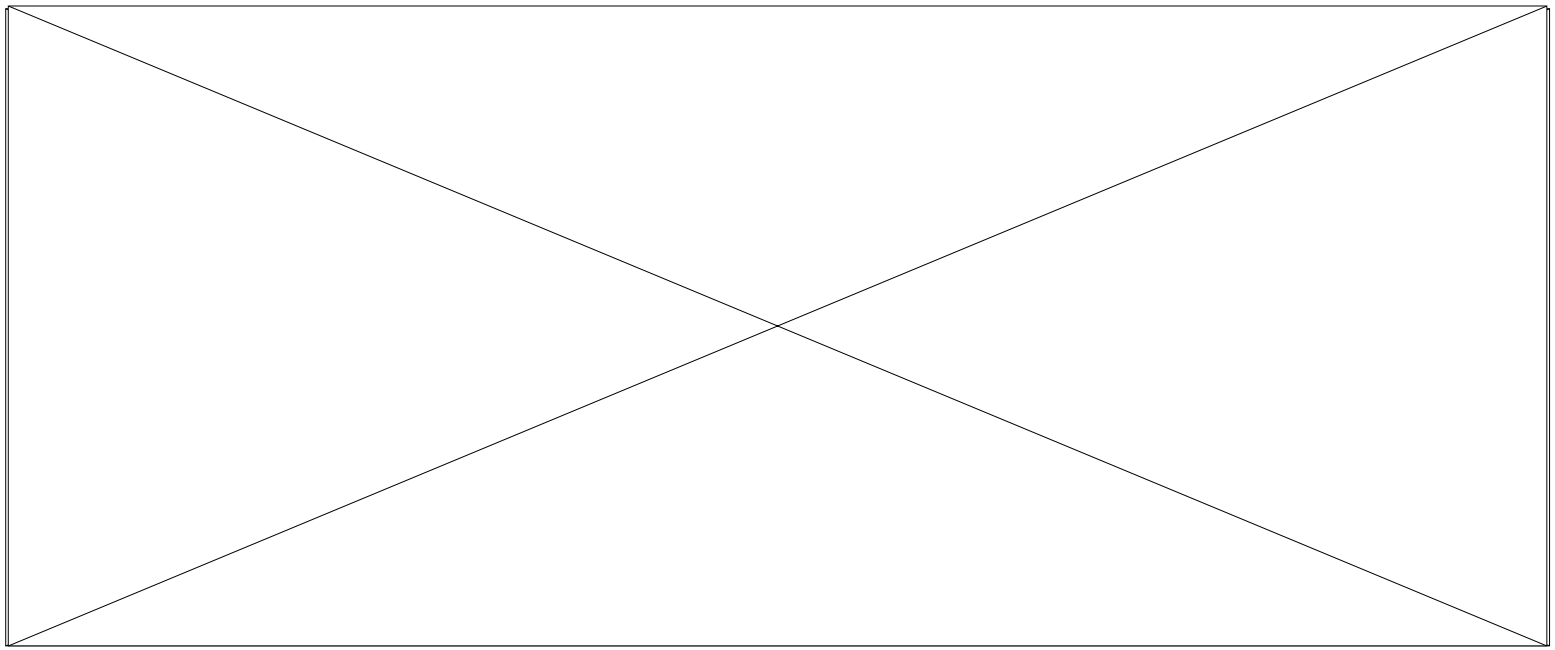
Agenda

- Introduction – EnerDel path to commercialization
- Company structure and organization
- Current strategic alliances / collaborations
  - Argonne National Laboratory
  - USABC
  - Itochu
- EnerDel Business Opportunities
  - USABC programs
  - Th!nk project
  - Government contracts (DOD)
- EnerDel strategy and technology
  - System Integration Solutions
  - Technology for HEV
  - Technology for PHEV and EV
  - Competitive advantages
  - Manufacturing
- Intellectual Property

EnerDel - path to commercialization

- **Covering all market opportunities in automotive electrification of the drivetrain:**
  - **Hybrid Electric Vehicle (HEV)**
    - **USABC Phase 2 program**
    - **Sampling of cells to potential customers**
    - **Unveiling of functional prototype packs**
  - **Plug-in Hybrid Electric Vehicle (PHEV)**
    - **USABC program for development of PHEV technology**
  - **Electric Vehicle (EV)**
    - **Th!nk Development and Supply Agreement**
- **Pursuing other market opportunities**
  - **Other automotive – Heavy duty, scooters, electronic braking, etc.**
  - **Government contracts - military**

Target Applications
- HEV, PHEV, EV-



- **Power & Energy Balance**

	HEV	P-HEV	EV
Power (Assist)	High	Medium	Lower
Energy (Distance)	Lower	Medium	High

HEV – PHEV - EV

Examples of HEV models:

Toyota Prius

Lexus RX 400h

Lexus GS 450h

Honda Civic

Examples of PHEV model:

Chevrolet Volt – GM E-Flex

Examples of EV models:

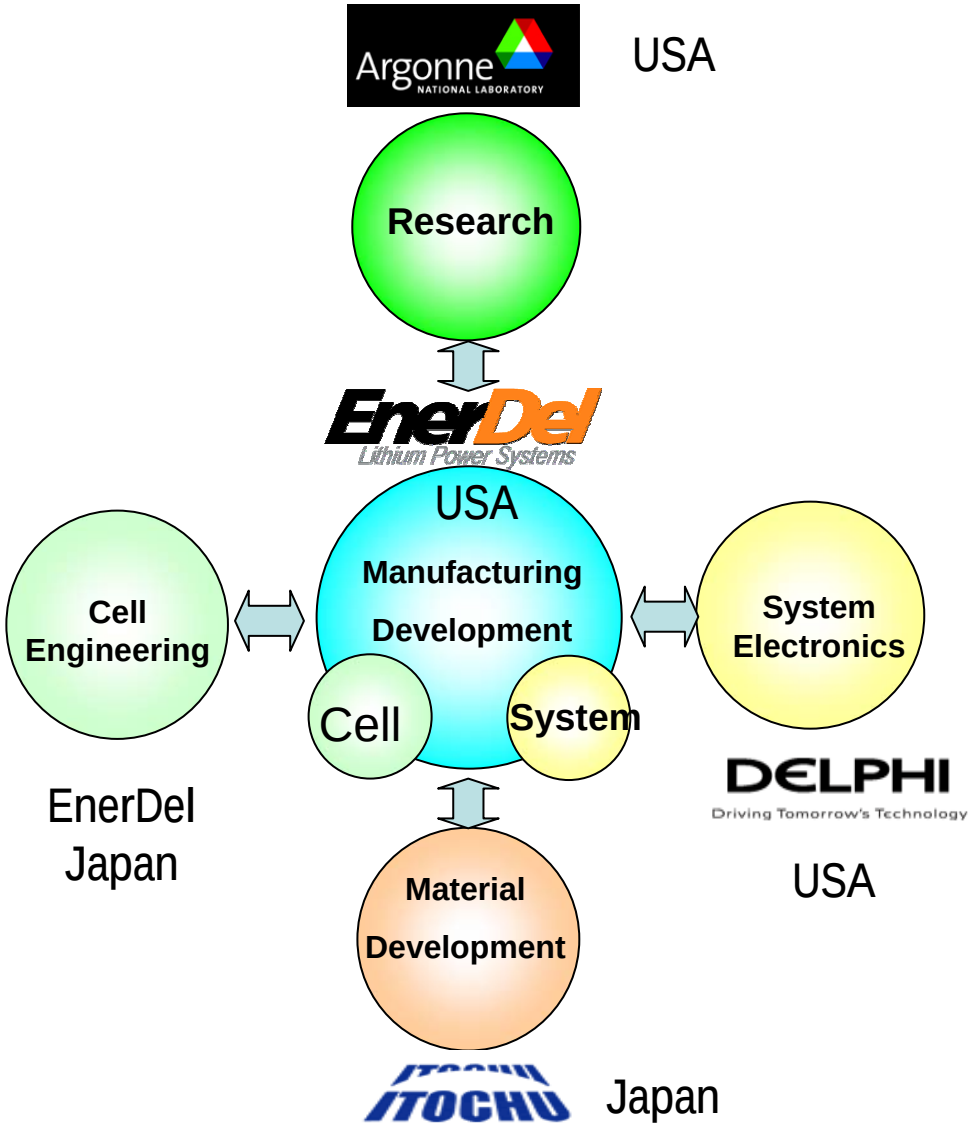
Tesla EV Roadster ↑

Think EV ↓

EnerDel Background

EnerDel Operation

- **Established**
  - **October, 2004 - EnerDel**
    - **Ener1 Lithium Group : 1990**
    - **Delphi Lithium Group : 1998**
- **Location**
  - **Indianapolis, IN**
- **Employee**
  - **55 Employees + EnerDel Japan**
- **Main Product**
  - **Lithium Ion Cell and Pack for Automotive Applications**
- **Existing Space**
  - **General purpose plant area: ~ 68,000 ft^2**
    - **Dry room facility: ~ 5,000 ft^2**
  - **Office area: ~ 24,000 ft^2**
  - **Total area: ~ 92,000 ft^2**



EnerDel's Business

2007 Main Business Milestones

- **USABC**
  - **HEV Phase 1 – completed. Testing ongoing.**
  - **HEV Phase 2 – approved and purchase order received**
  - **PHEV Phase1- approved and purchase order process**
- **Cell sampling to customers**
  - **Shipment of samples to potential customers taking place**
  - **Schedule: August/September 2007**
- **Three (3) prototype packs**
  - **Functional sample capable of being tested in a real vehicle**
  - **Schedule: Mid-September 07**
- **Demonstration vehicle**
  - **Vehicle powered by EnerDel HEV battery**
  - **Schedule: December 2007**
- **Development contract**
  - **Development contract from automotive company**
  - **Schedule: Q4 2007**

USABC Contract

- **U.S. Advanced Battery Consortium (USABC),**

  A part of the United States Council for Automotive Research (USCAR), an organization founded by *DaimlerChrysler, Ford and General Motors* that works with the Department of Energy (DOE) to strengthen America's auto industry through cooperative development of advanced technologies.

- **Current USABC contracted developers**

Contract Developer	Focus Chemistry	Main Factory Location
EnerDel	**LMO/LTO**	***USA***
Johnson Control / Saft	LNO/Graphite	(France)
A123	FePO4/Graphite	China-OEM
Compact Power (LG)	LMO /Graphite	Korea

Th!nk project

- Revenue opportunity of $70 million – potentially largest li-ion contract for automotive to date.
- Supply Agreement with development phase
- Development phase
  - March 2008 – delivery of prototype packs
  - July 2008 – delivery of pre-production units
  - Meeting the performance criteria and deliverables leads to commercial deliveries
- Production revenues starting from end 2008/early 2009 – depends on qualification testing
- Revenues for 2009 and 2010

EnerDel Battery Systems

EV / HEV Battery Systems Integration Experience

- 1993 Delphi 22-ft Series Hybrid Shuttle Bus (Indy Shuttle, PbA)
- 1995 GM EV1 Production Program (PbA, NiMH)
- 1996 GM Electric S-10 Production program (PbA, NiMH)
- 1996 GM / Allison Electric and Hybrid Bus programs – Luxembourg, New York City (PbA)

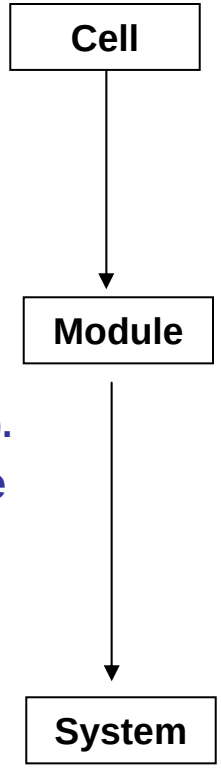
- 1997 Li-ion solutions for: automotive (SLI), electric "Warrior" bicycle, stand-by power (BESS)
- 1996 Delphi 108V (PbA) Neighborhood Electric Vehicle

- 1999 Dual Voltage FAS Parallel Hybrid Truck (PbA, GM Truck)
- 1999 Delphi 14/42-V Li-ion, Electrical Architecture (Renault Scenic)
- 2001 Next Generation Wheel Chair - 65V fully integrated Lithium Power System
- 2003 Personal Mobility – 80V fully integrated Lithium Power System (production ready)

- 2004 EnerDel Inc. - JV LAUNCH
- 2005 Lithium Power System Development:
  - 12 Volt, 4 Ahr Module
  - 24V, 7 Ahr Module
  - Automotive Suspension – 350V fully integrated pack
  - Hybrid Bus Program – 700V (200 kW) fully integrated pack

EnerDel Lithium Ion Battery System for HEVs

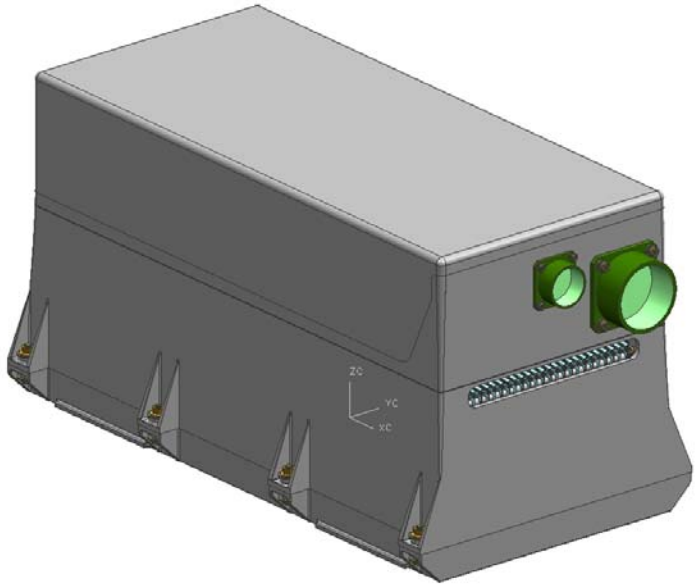
- **Lithium Ion Cell**
  - **Outstanding safety**
    - **No Thermal Runaway**
  - **Excellent longevity**
    - **10+ year cycle life**
  - **High power performance**
    - **3-5 times bigger power density than existing HEV battery (Ni-MH).**
  - **Excellent low temp. Performance**
    - **Cold Cranking**
- **Battery System Integration**
  - **Automobile class electrical battery management system.**
  - **Automobile grade mechanical design**
  - **Thermal management design**



System Design Features

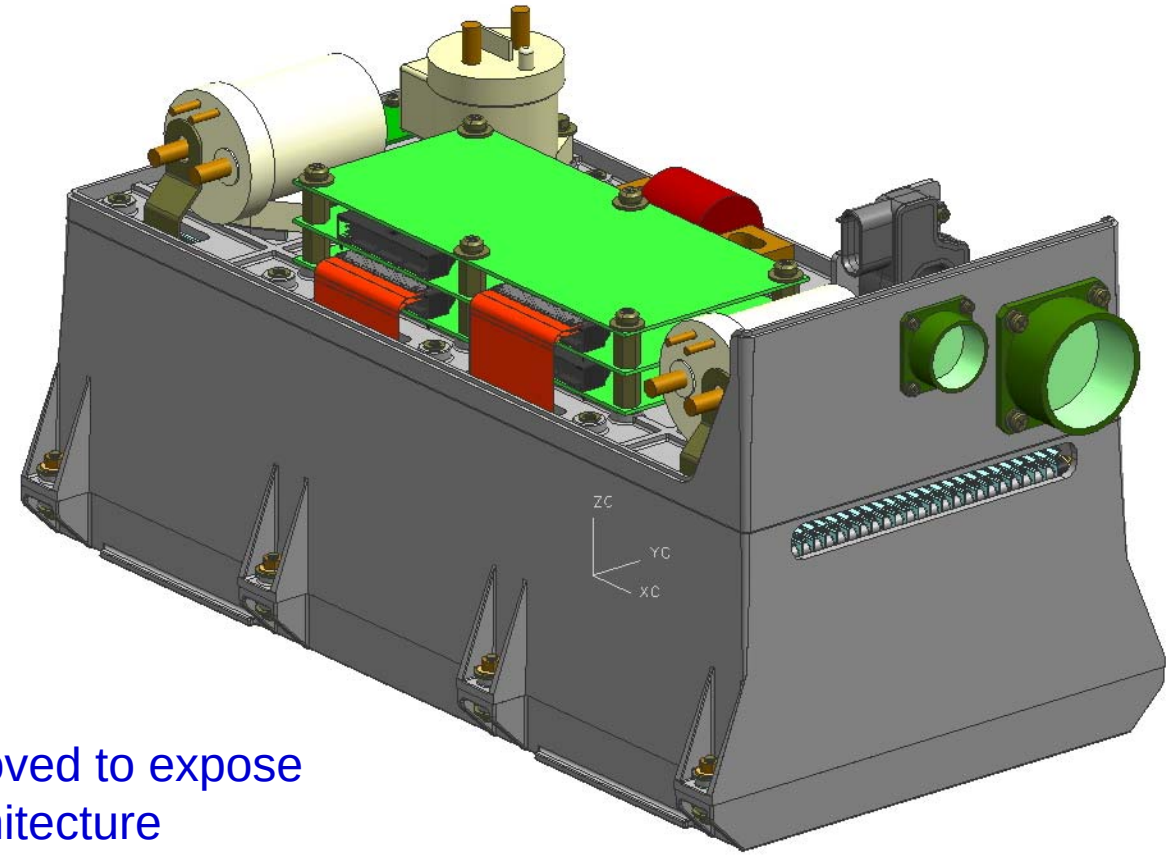
- **Safety**
  - **System control redundancy**
  - **Ultra - low voltage assembly (non-lethal)**
- **Packaging Efficiency**
  - **Stacking efficiency of prismatic cells**
  - **Elimination of discrete wires for voltage / temperature sensing**
- **Architectural Flexibility**
  - **Modular design offers multiple arrangement configurations**
- **Mechanical Robustness**
  - **Designed for ease of assembly / error proofing features**
- **Thermal management**
  - **Design allows for air or liquid cooling**

EnerDel 5Ah cell / Battery Pack



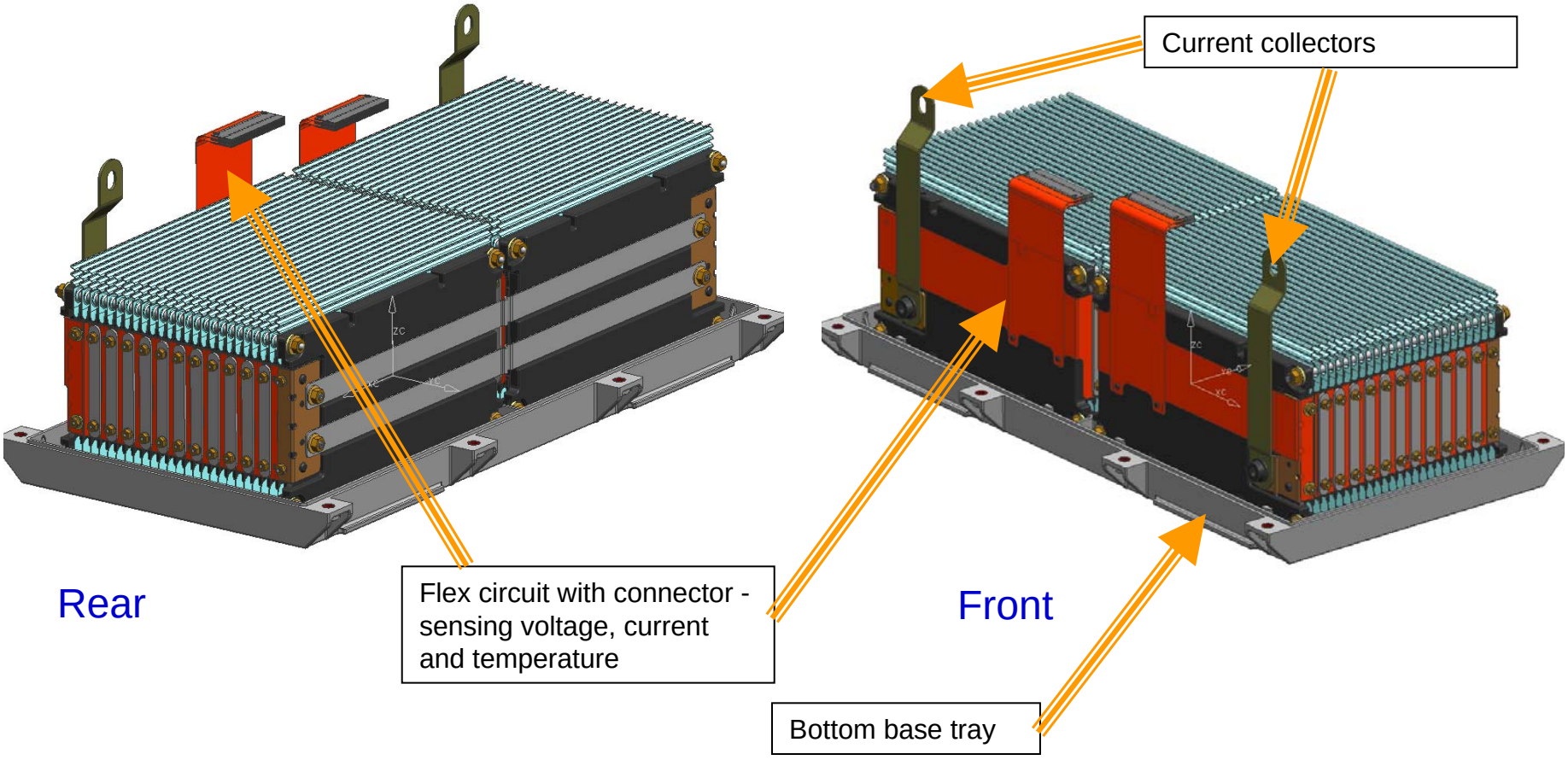
- **EnerDel is developing HEV battery packs with battery management systems for lithium-ion cells.**

HEV Battery Pack

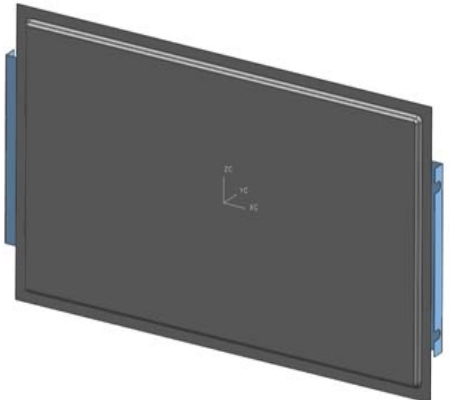


Cover removed to expose control architecture

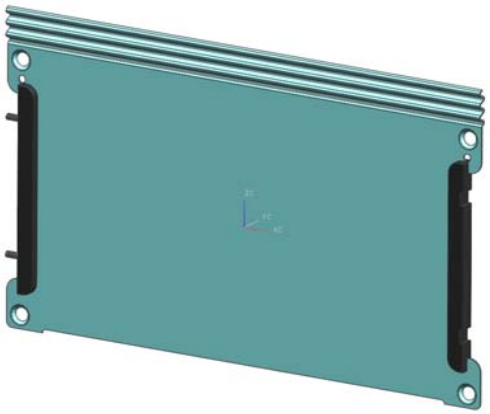
HEV Battery Pack Base and Modules



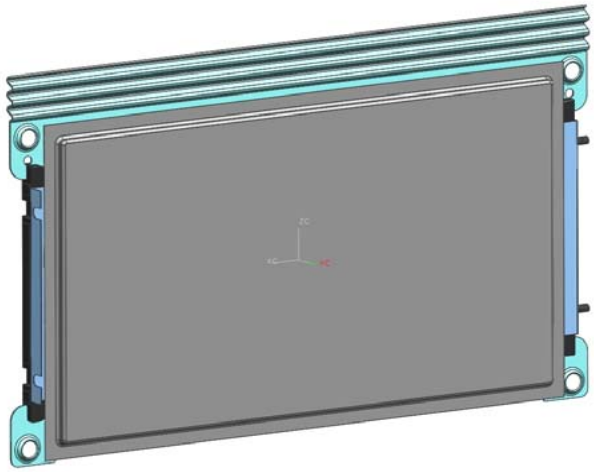
Cell & Heat-Sink Assembly



Individual Cell



Heat-Sink Assembly



Assembly View of Cell Positioned on Heat-Sink

First Prototype Packs

EnerDel Cell Technology for HEV

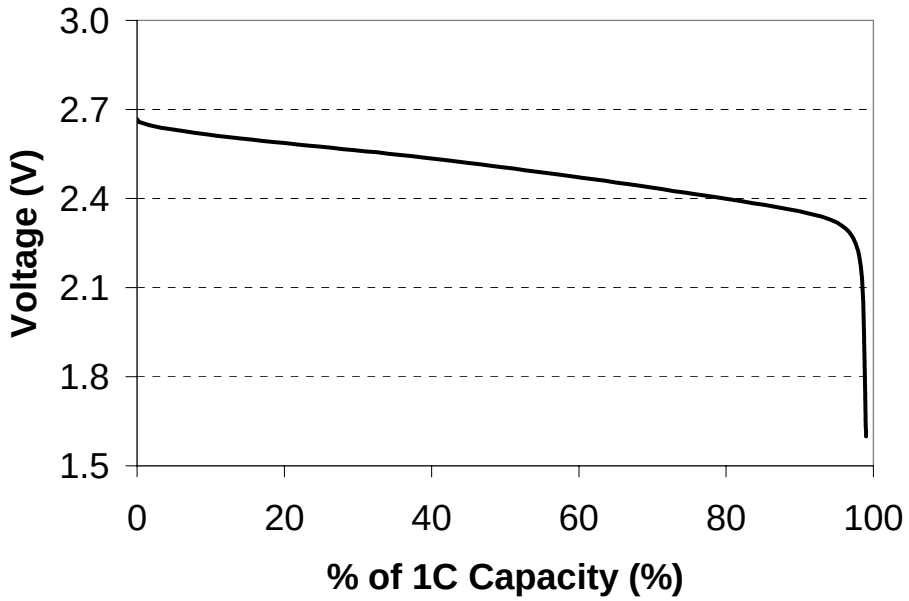
Chemistry Design - HEV

Cathode Group	Group A (Nickel Base)	Group B (Iron base)	Group C (Mn Base)		Group C-1 (Mn Base) - PHEV / EV	Group C-2 (Mn Base) - HEV
Cathode	$LiNi_XCo_XO$	$LiFePO_4$	$LiMn_2O_4$		$LiMn_2O_4$	$LiMn_2O_4$
Anode	Graphite	Graphite	Graphite		Hard Carbon	*LTO*
Advantage	Capacity	Safety Cost	Cost Power		High Power Longevity Low Temp. Safety	High Power (+) Longevity (+) Low Temp (+) Safety (+)
Disadvantage	Safety Price	High Temp. Voltage	High Temp. Longevity		Energy Efficiency	Slightly Lower Energy
Company					*EnerDel*	*EnerDel*

* Information on other systems is based on available market information and might not be fully accurate.

EnerDel's Chemistry for HEV Application

- **Positive Active Material: $LiMn_2O_4$- spinel (LMO)**
  - $LiMn_2O_4 \leftrightarrow Li_{1-x}Mn_2O_4 + xLi^+ + xe^-$
- **Negative Active Material: $Li_4Ti_5O_{12}$ (LTO)**
  - $Li_4Ti_5O_{12} + xLi^+ + xe^- \leftrightarrow Li_{4+x}Ti_5O_{12}$



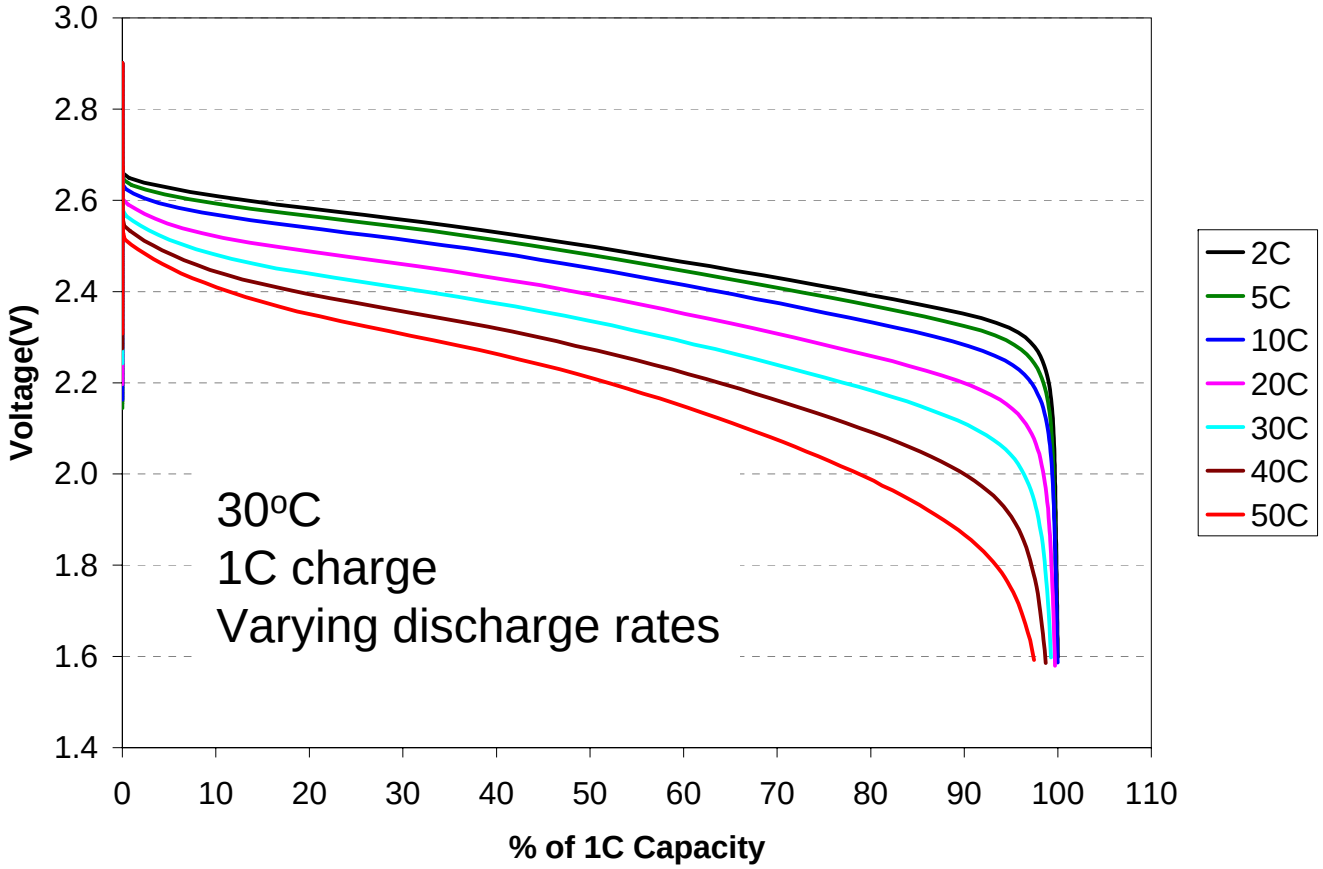
1C discharge
30°C

Cell Design

- **Prismatic**
  - **Case Neutral**
  - **Good heat dissipation**
  - **Flexible form-factor**

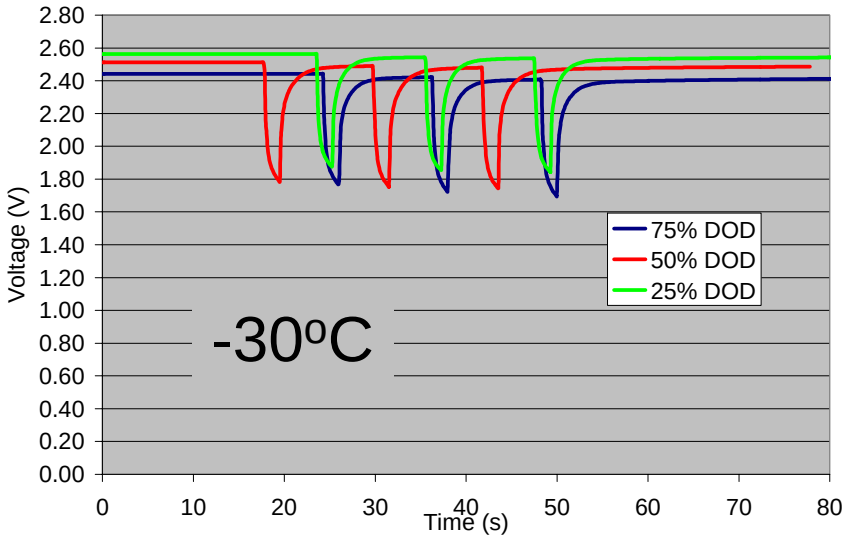
	CD Size	A5 Size
Nominal Capacity	1.8 Ah	5 Ah
Nominal Voltage	2.5V	2.5 V
Dimensions (connections included)	145mm W, 130mm L, 5mm T	200mm W, 111mm L, 5.8mm T
Packaging	Metal or Laminate	Metal or Laminate

Rate Capability of 1.8 Ah Cells

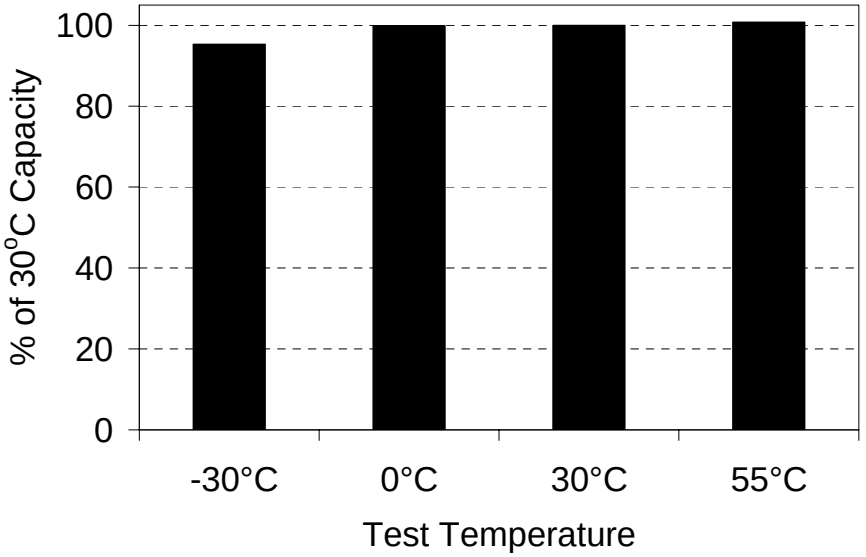


- **High discharge efficiency for rates up to 50C.**

Low Temperature Performance



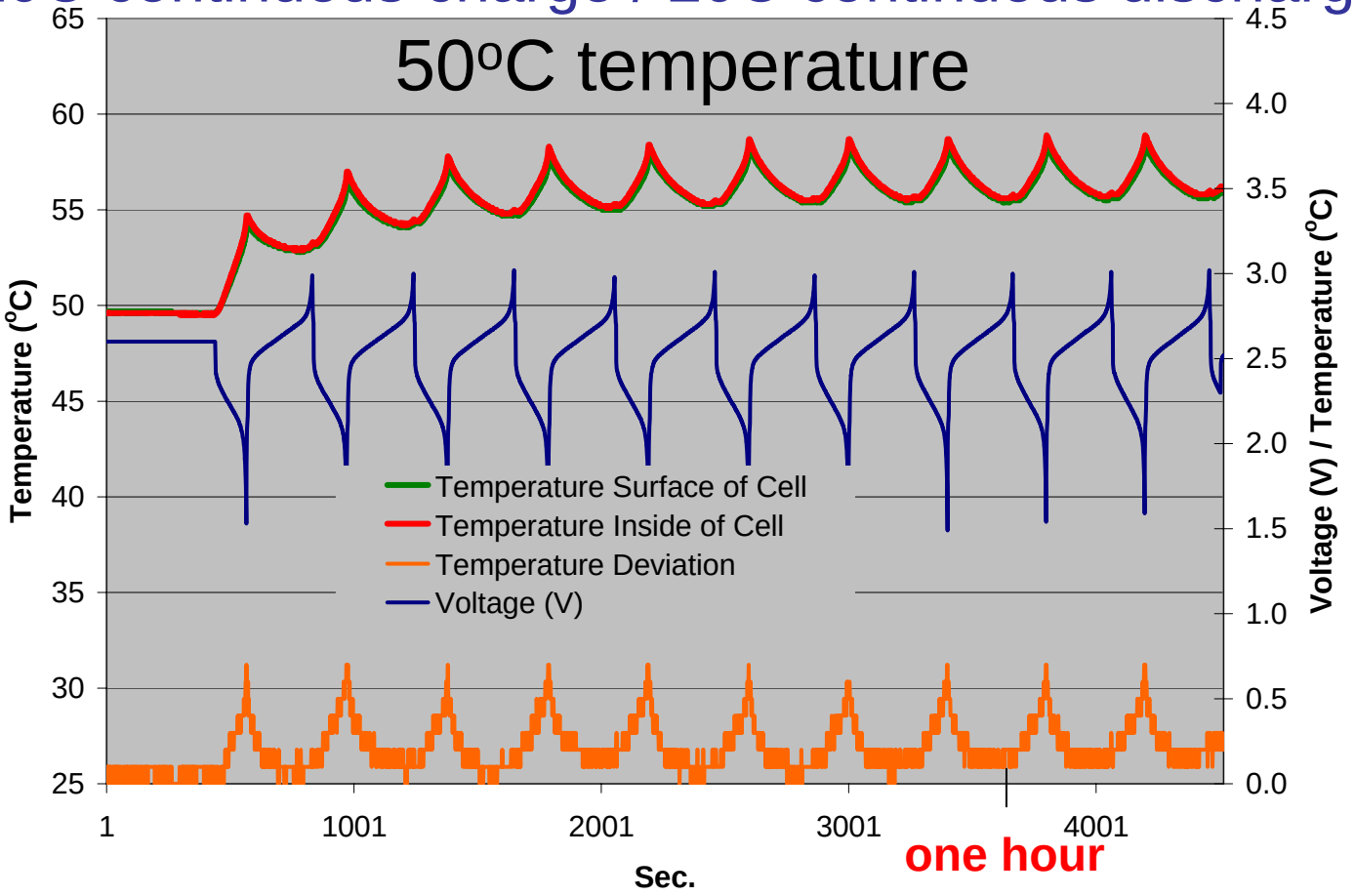
Cold Cranking
Equivalent to 5kW of power



1C Discharge

- **High power and full discharge capability at low temperatures.**

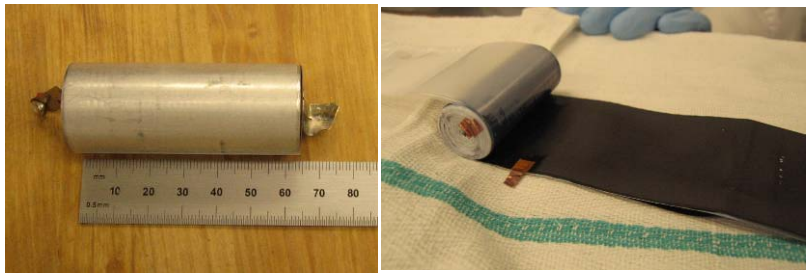
Thermal Tests at 50°C
10C continuous charge / 20C continuous discharge



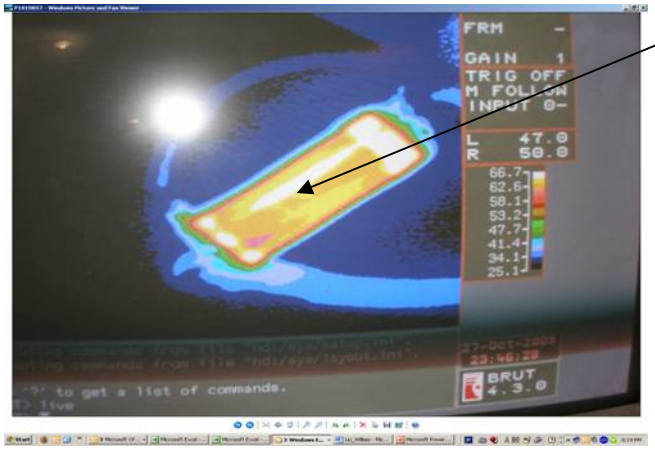
- **The temperature of the cell does not exceed 60°C during continuous charge and discharge at ambient temperatures of 50°C.**

Excellent High Rate & Thermal Performance

Competitors

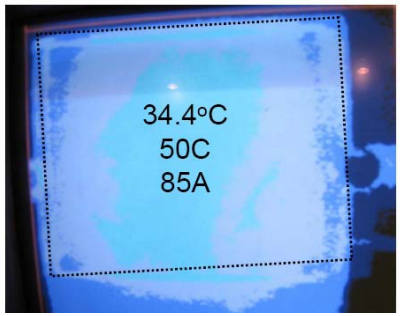


EnerDel



<66.7°C

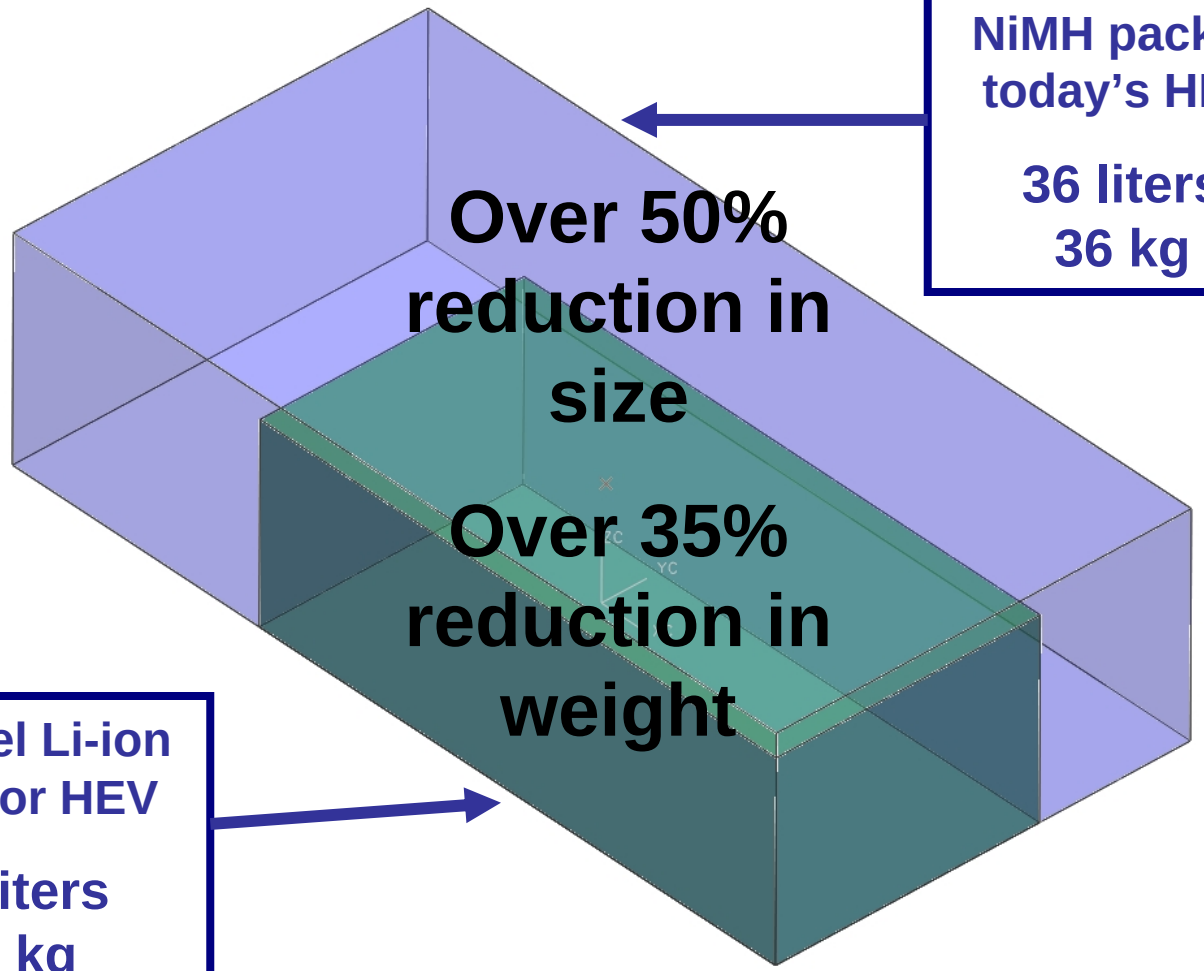
30A Continuous Discharge
Competitors 2.3Ah Cell



No hotspots

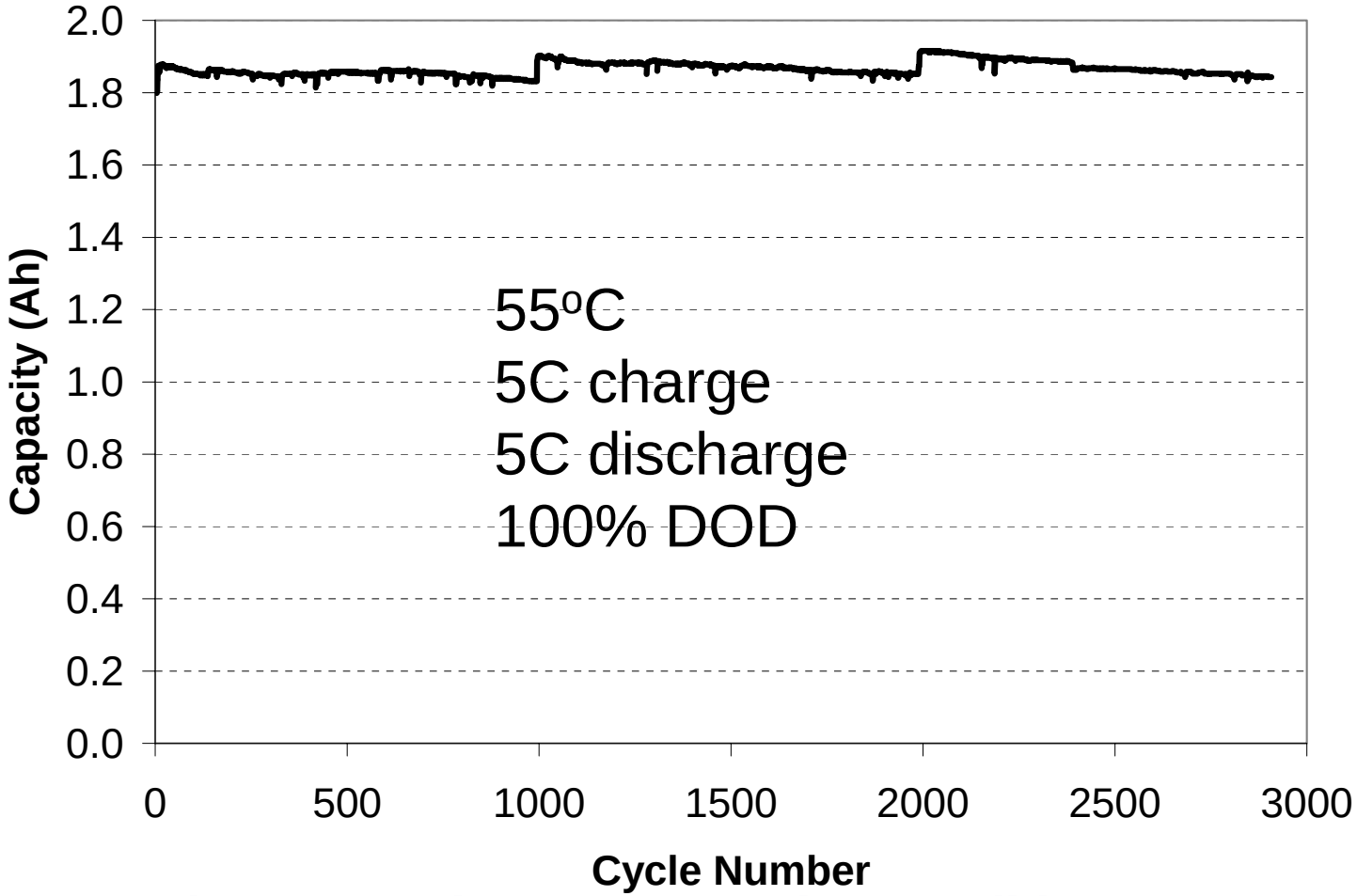
85 A Continuous Discharge
EnerDel 1.7Ah Cell

EnerDel Li-Ion vs NiMH HEV pack



Control electronics not included

Cycle life test under high temperature

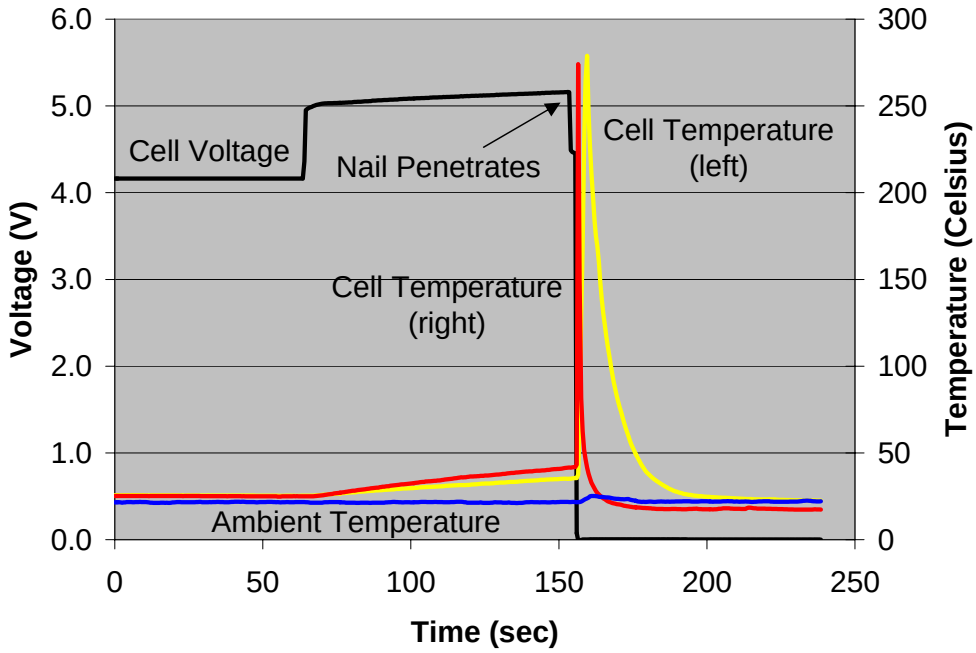


- **No capacity loss under severe cycling conditions.**

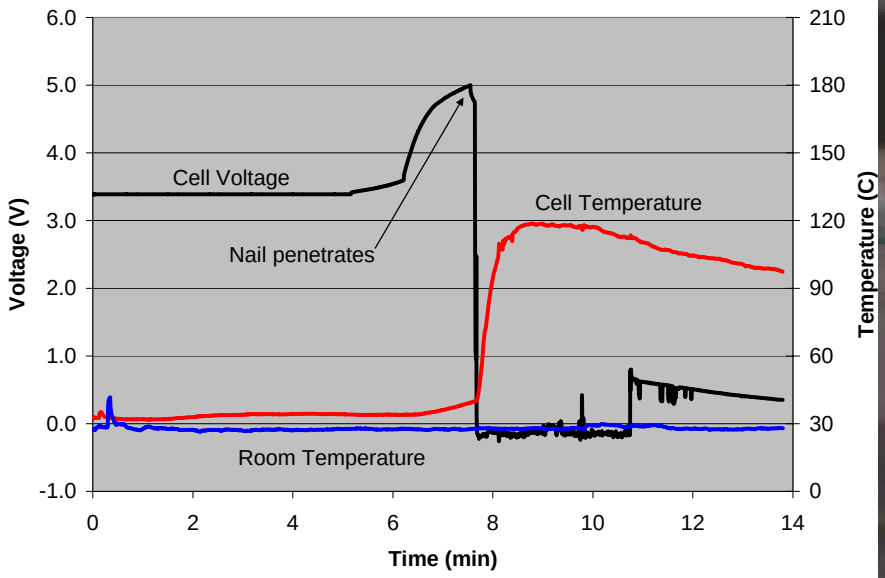
Abuse Testing

- **Overcharge and Nail Penetration Test**
  - **4C rate for 90 seconds from 100% charged state.**
  - **Corresponds to 10% overcharge.**
  - **Then nail penetrates.**

18650 Commercial Cell
Overcharge and Side Nail Penetration

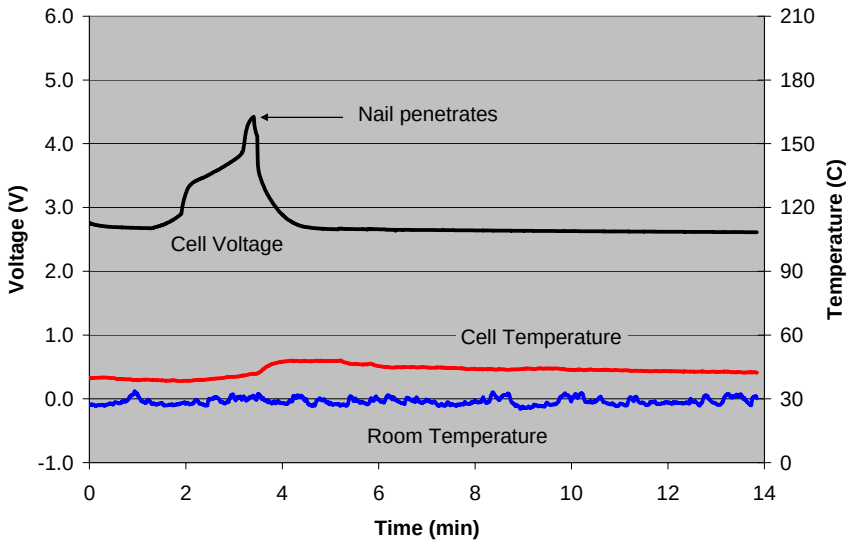


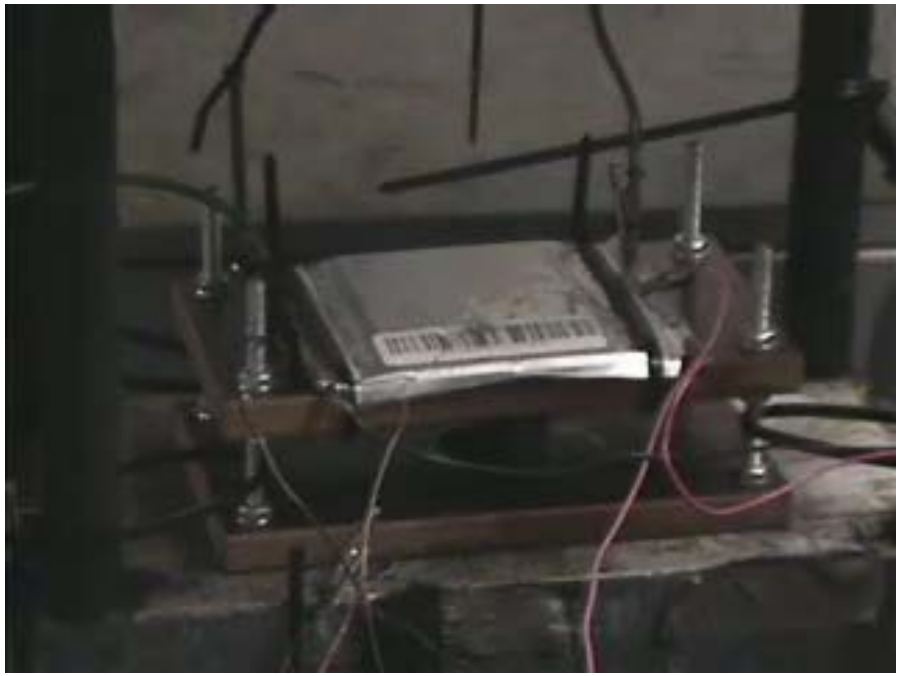
26650 Commercial Cell
Overcharge and Side Nail Penetration



- **Cover of cell popped off from case.**

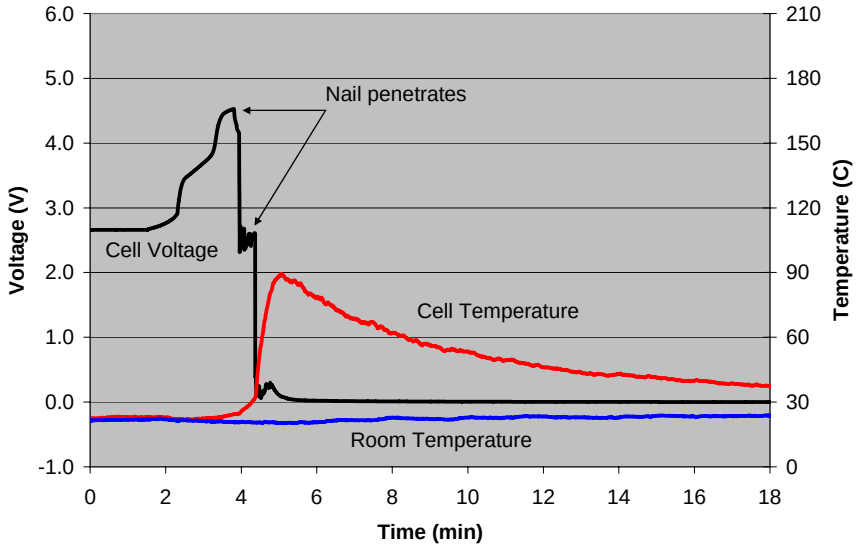
EnerDel Gen1 Cell
Overcharge and Nail Penetration





- We attempted to short the cell with a nail penetration from the side and top.
- We did 5 trials and none of them caused the cell to short.
- This is a typical result for our cell.

EnerDel Gen1 Cell
Overcharge and Nail Penetration



- **In order to obtain a short, the cell was manually shorted.**
- **The nail was inserted into the cell multiple times and moved around to ensure that a short occurred.**

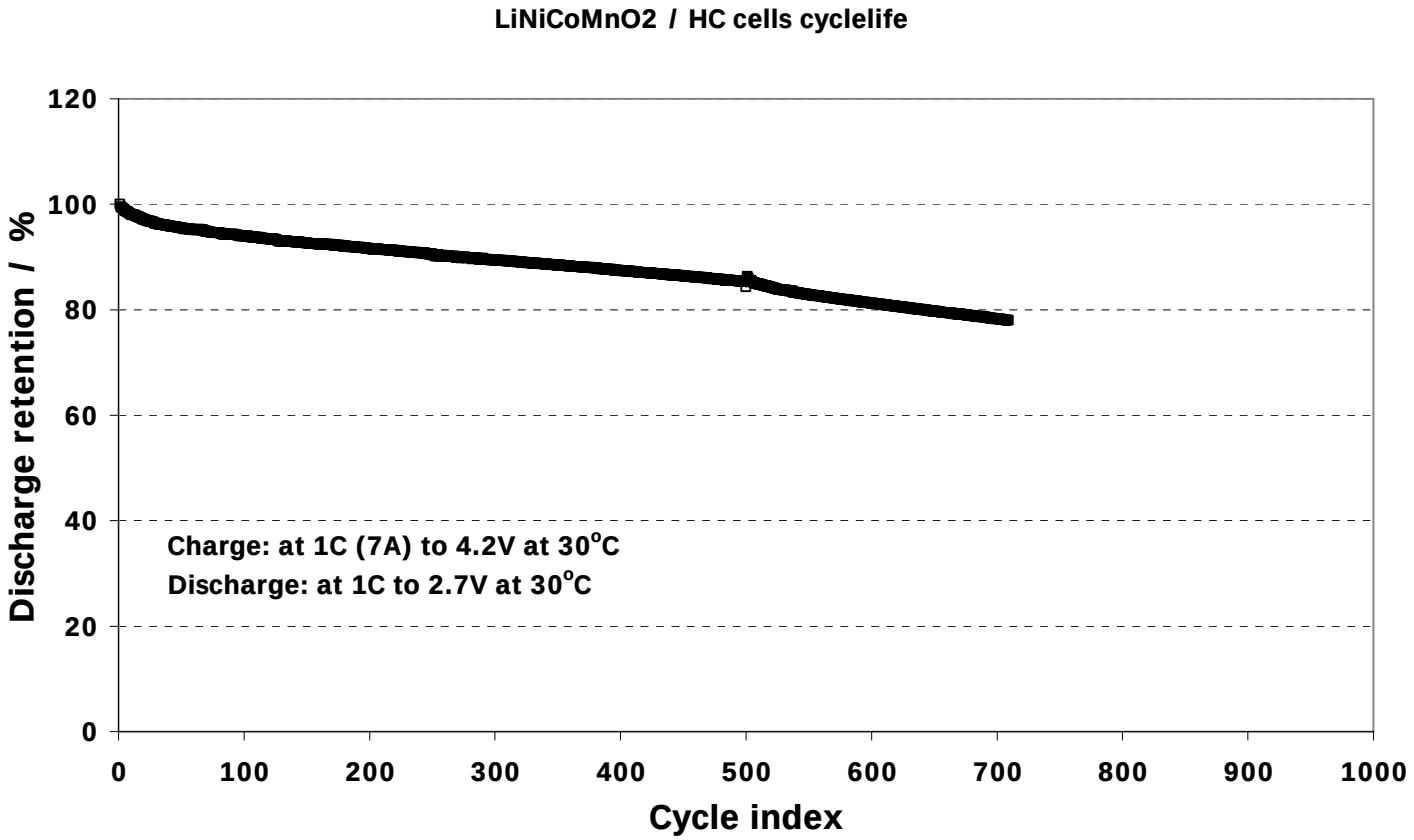
EnerDel Battery Advantages

- **High Power**
- **Safety**
- **Longevity**
- **Temperature Performance**
- **Compact design**

http://enerdel.com/

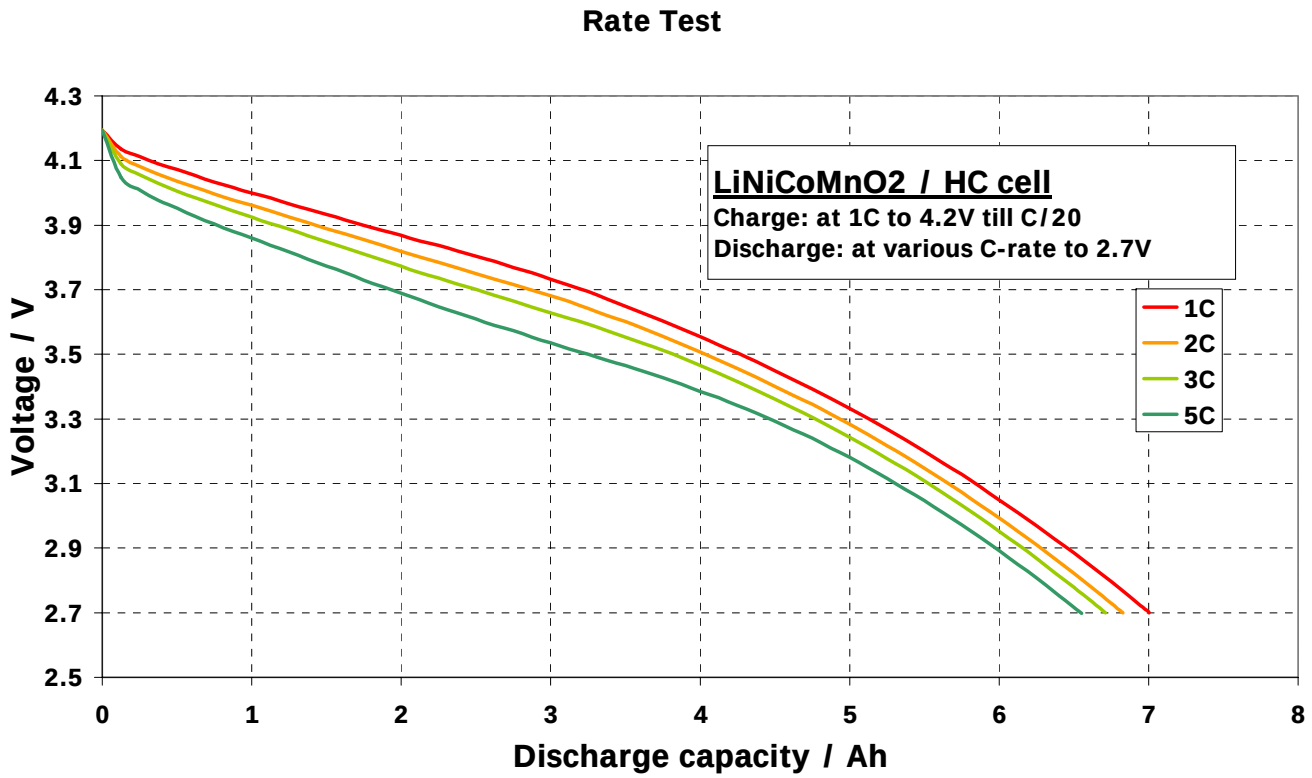
High Energy Density Solution for PHEV and EV

EnerDel testing of cycle life



EnerDel cycle life testing of 7Ah cell with chemistry for high energy density – demonstrates good cycle life. Good base line and other EnerDel and industry test data demonstrates further improvements capable.

EnerDel testing of rate capability



Good rate capability from 1C to 5C for electric vehicle application.

Intellectual Property

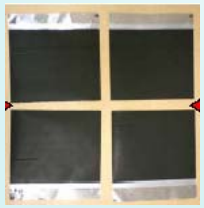
Manufacturing

Process Flow

Cell Manufacturing

Electrode "Coating" Process

- Mixing
- Coating
- Calendering
- Slitting & Punching



Cell Assembly

- Electrode Stacking
- Case Assembly
- Electrolyte Filling
- Sealing

Final Assembly & Formation

- Final Cell Assembly
- Formation Process

System Integration

Pack Assembly

- Cell Interconnect & Electronics
- Casing & Pack Assembly
- Final Test

Scale-up timeline